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WIND SPEED AND LATENT HEAT FLUX RETRIEVED BY SIMULTANEOUS OBSERVATION OF MULTIPLE GEOPHYSICAL PARAMETERS DERIVED BY AMSR-E

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1. INTRODUCTION

The satellite measurement technique enables us to monitor the climate conditions over the wide area of the earth surface in a very short time. In particular, monitoring the latent heat flux is very important, as the variation of the amount of water vapor affects the large scale climate change through the cloud genesis and the evaporative cooling at the ocean surface. Usually, the latent heat flux can be obtained from the measurement of sea surface temperature (SST), sea surface wind speed (SSWS), and specific humidity near the sea surface by the bulk formula,

$$Q = L\rho C_e (q_s - q_a) U_{10} \quad (1),$$

where L indicates the latent heat of evaporation, ρ, the density of the atmosphere, Ce, the bulk coefficient, and U10, wind speed at height of 10m. qa and qs respectively show the specific humidity at height of 10m and that saturated at the SST, multiplied by 0.98, which is a typical value of the water vapor reduction at the sea surface with 35‰ (List 1949).

Advanced Microwave Scanning Radiometer (AMSR) on Advanced Earth Observation Satellite II (ADEOS-II) and AMSR on Earth Observing System (AMSR-E) on Aqua simultaneously measure the SSWS, SST, and integrated water vapor (IWV), and therefore the surface humidity. The instantaneous value of the latent heat flux, which should physically consistent in its meaning, can be obtained by these parameters.

Contrastively, combined use of the several sun-synchronized satellite sensors can cause a time lag of observations of the individual parameters, caused by the orbital difference of satellites. The diurnal cycle of parameters in eq.(1) (Clayson and Weitlich 2007) would bring the inconsistency and the uncorrectable ambiguity into the latent heat flux derived by parameters measured at the different time (time-lagged latent heat flux), as the local time of the each observation of individual satellites is different from every other (Figure 1). The lagged observation of the latent heat flux (Q') equals neither the instantaneous value of the latent heat flux (Q) nor the time average of Q (Qave). Therefore, it is very difficult to evaluate the accuracy of the "time-lagged" satellite-derived latent heat flux by in situ observation. The instantaneous latent heat flux could be directly compared and evaluated by the in situ observation.

On the other hand, the accumulation of the individual

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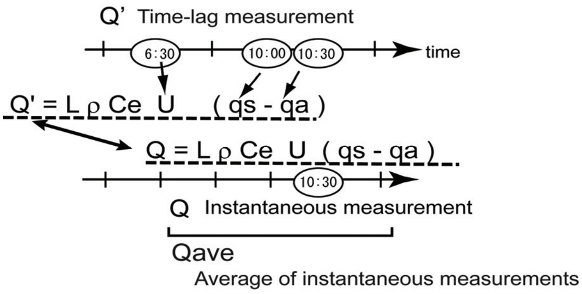

Figure 1: Schematic view of the difference between the time-lagged latent heat flux and the instantaneous latent heat flux.

errors of the physical parameters should affect the accuracy of the satellite-derived latent heat flux. In particular, the uncertainty of the SSWS should have a serious impact on the computation of the latent heat flux especially at its large value, because the role of the SSWS for the latent heat flux significantly increases with the larger SSWS.

Konda et al. (2006), hereafter KSEA06, attempted to correct the change of the brightness temperature (BT) due to the angle between the sensor azimuth and the in-situ wind direction (relative wind direction, hereafter RWD). The change of the BT due to the RWD allows some errors to creep into the SSWS retrieval. The error approximately amounts to 2-3 ms-1 (Wentz 1997, Konda and Shibata 2004). The method of KSEA06 reduces the error caused by the RWD effect by 60%.

However, the validation was based on the data for only one month, and the collocation was obtained only in the high latitudes over 50 degrees because of the orbital difference. Moreover, recent studies (Liu et al. 2007, Liu and Xie 2008) point out that the radar scatterometer is sensitive not to the ocean wind vector but to the stress, which can be affected by the vector difference between the ocean winds and currents. It is needed to make further validation by the in situ measurement of the ocean wind under other climatic regimes and for the longer period.

Recently, Konda et al. (2009) validated the SSWS and the latent heat flux derived by AMSR-E by the measurement at the surface mooring buoy in the northwest Pacific. The objective of this paper is, according to Konda et al.(2009), first to validate the RWD effect correction in the wind speed derived by AMSR and AMSR-E by the ocean surface buoy data, and second to evaluate the impact of the simultaneous measurement of boundary layer parameters on obtaining the physically consistent latent heat flux.

2. DATA AND METHOD

In this study, the AMSR-E SSWS (U_K) is retrieved from the measured BTs provided by Japan Aerospace Exploration Agency (JAXA) in a form of the AMSR level 1B data set, according to the method described in KSEA06. We also use the latest versions 4 and 5 (version 4 before February 2007) of the AMSR-E standard product (U_S) for the purpose of comparison. The difference between U_K and U_S is almost attributable to that of the method how to correct the RWD effect.

As KESA06 evaluated the U_K by using the SSWS measured at the Tropical Atmosphere and Ocean project (TAO) array in the tropical Pacific (McPhaden 1995), we will conduct another evaluation in the mid latitude. Pacific Marine Environment Laboratory (PMEL)/ National Oceanic and Atmospheric Administration (NOAA) operates the Kuroshio Extension Observatory (KEO) buoy at 144.6°E, 32.4°N, while Japan Agency for Marine-Earth Science and Technology (JAMSTEC) does JAMSTEC KEO (JKEO) buoy at 146.5°E, 38.0°N. We will use the high resolution (every 10 minutes) and the real time daily average data for validation. These buoys are measuring the surface meteorology and the underwater physical properties at the south and the north across the Kuroshio Extension SST front (Cronin et al. 2008).

The method we use to correct the RWD effect on AMSR-E SSWS is same as that of KSEA06. A look-up table based on the relationship between BTs with the vertical ($BT36_V$) and the horizontal polarization ($BT36_H$) at 36.5 GHz is defined as,

$$PS36_T = PS36(SST, IWV, CLW, U6, RWD) \quad (2).$$

, where an index, PS36, representing the partial shift of the $BT36_H$ caused by the SSWS, is determined as the deviation from the bottom value of $BT36_H$ at each SST. See KSEA06 for details of these definitions.

The latent heat flux can be obtained only from the AMSR-E products. We will use the standard products of the SST and the IWV. The atmospheric specific humidity is to be computed by the empirical relationship between the precipitable water and the mixing ratio (Liu and Niiler 1984). As AMSR-E provides these variables without a time lag, instantaneous latent heat flux at individual observation pixels can be obtained. In contrast, traditional estimation of the surface turbulent heat flux is obtained from parameters, each of which is derived by the sensors on the different satellites. That can cause the time lag between the boundary layer parameters in eq (1) (Fig. 1).

The impact of such time lags of these parameters is evaluated by a comparison between the latent heat flux measured at TAO and that obtained by the SST, SSWS, and surface specific humidity derived by Advanced Very High Resolution Radiometer (AVHRR) on NOAA-17, SeaWinds on QuikSCAT, and AMSR on ADEOS-II. Considering the difference of the orbit of these satellites, level 3 daily map-projected data both in the morning and the nighttime are used

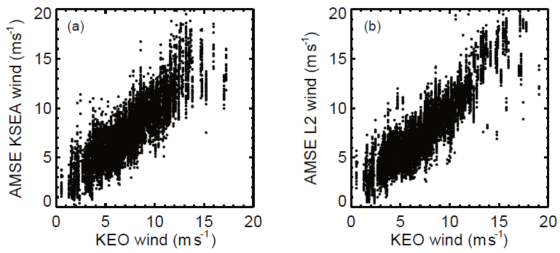

Figure 2 Scatter plot of (a) the KEO wind speed and the SSWS derived according to KSEA06, and (b) the KEO wind and the SSWS of AMSR-E standard product.

RESULTS

In the mid latitude, AMSR-E SSWS (U_K) is compared with KEO buoy wind. Fig. 2(a) shows the result of the comparison between U_K and the KEO wind of 8881 collocations from 2004 June to 2007 December. The RMS error is 1.7 ms^{-1}. In the same way, the comparison with AMSR-E standard algorithm, U_S, (Fig 2(b)) of 9454 collocations shows that the RMS error is 1.6 ms^{-1}. The difference between the KESA06 method and the standard algorithm to correct the RWD effect is not significant. Both of the comparisons show that the error at the KEO is slightly worse than in the tropical region (1.1 ms^{-1}) reported by KSEA06.

Additionally, we conducted a comparison of the SSWS at the JKEO, another buoy platform in the north of the Kuroshio Extension. The comparison is done for the data derived in 2007 because JKEO was deployed in February 2007. The SSWS at JKEO is the daily average because of the telemetry. The RMS error of the daily average of U_K at JKEO is 2.6 ms^{-1}.

The error of the daily average U_K at KEO (2.8 ms^{-1}) is almost the same as that at JKEO. RMS errors of Us at JKEO and KEO are 2.6 ms^{-1} and 2.9 ms^{-1}, respectively. The spatial difference of the error does not seem to be significant.

We consider that there is no significant difference between the SSWS obtained by the method of this study and that of the standard algorithm. On the other hand, the large error in both of the north and south of the Kuroshio Extension suggests that more validation using the in situ observation in the mid latitude is needed to improve the accuracy of the SSWS.

The uncertainty of the SSWS estimation should have a serious impact on the computation of the latent heat flux, because the role of the SSWS for the latent heat flux shows a marked increase with increasing SSWS. We conduct a comparison of the instantaneous observation of the latent heat flux derived by AMSR with the in situ observation at TAO arrays from April to September, 2003. Generally, the AMSR latent heat flux agrees well with the in situ observation, but tends to be overestimated when the in situ latent heat flux is large (not shown).

The first line in Table 1 shows the result of the comparison between the instantaneous observation of the latent heat flux and the other parameters by AMSR and TAO. As the AMSR latent heat flux derived here is internally consistent without a time lag, the error of the estimation is attributable to that caused by the accumulation of the individual measurement errors of the parameters.

When the latent heat flux is obtained by different satellite sensors, the latent heat flux to be dermined is not physically consistent as shown in Fig. 1, e.g., the SST, the SSWS, and the IWV are observed at different time. Considering the difference of equator crossing time, an example of validation is done using the latent heat flux derived by the TAO array, averaged during the morning (6AM – 10:30AM) and the nighttime (6PM – 10:30PM). The second low of Table 1 shows that the difference is 48.8 ± 68.3 Wm^{-2} (figure is not shown). Note that the mean difference here is the accumulation of the error of the individual satellite observations and the inaccuracy caused by the time-lagged observation of the SST, the SSWS and the IWV.

In order to extract the ambiguity of the latent heat flux due to the time-lagged measurement, a time-lagged latent heat flux is virtually computed by using only the TAO data, avoiding the contamination of the individual satellite estimation errors. Figure 3 shows a comparison of the latent heat flux computed from each variable at the corresponding satellite's equator crossing time (10:00 AM/PM for the SST, 6:00 AM/PM for the SSWS, 10:30AM/PM for the specific humidity) and the average of the instantaneous latent heat flux from 6:00 to 10:30 AM/PM.

The difference between these values is identified as the uncertainty of the latent heat flux caused by the observation of the individual variables with a time lag. The difference caused by this inconsistency in the latent heat flux amounts to -1.3 ± 44.3 Wm^{-2}. This is the ambiguity, which is more serious than the accumulation of the estimation errors of individual variables in eq (1), as described previously. The difference is characterized by the small bias and the large standard deviation. This suggests that the error caused by the time-lag between the individual measurements affects the inaccuracy rather than the bias.

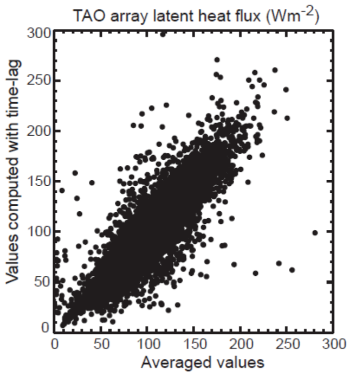

Figure 3 Scatter plot of the average of the instantaneous latent heat flux and the time-lagged latent heat flux using data at TAO array from April to September 2003.

It is almost the same as the boundary layer parameters as indicated in Table 1. It is not evident which parameter is the most responsible for the large standard deviation in the latent heat flux, which is a quite different point from the analysis of the instantaneous measurement. The multi-satellites observation of the latent heat flux necessarily includes such amount of error to the average in situ observation, even if each variable is observed correctly. This fact clearly explains the merit of the simultaneous observation of the boundary layer parameters, which is achieved by AMSR and AMSR-E.

4. DISCUSSION AND CONCLUSIONS

The correction of the RWD effect on the retrieval of the SSWS by AMSR and AMSR-E has been validated using the mid-latitude ocean surface buoys (KEO and JKEO) as well as the tropical Pacific (TAO). The accuracy of the SSWS derived by the method using the look-up table proposed by KSEA06 is almost same as that of the standard algorithm. However, both of them tend to overestimate in winter and underestimate in summer. Further validation is needed to determine the source of such systematic error.

The importance to obtain the accurate SSWS by AMSR and AMSR-E for the instantaneous latent heat flux is proposed in this study, which indicates the possibility to monitor the earth environment by microwave sensors. We showed that the time-lagged measurement of the boundary layer parameters measured by different sun-synchronized satellites brings an uncorrectable ambiguity into the estimation of the latent heat flux. It was found that the typical value in the tropical Pacific amounts to about 44.9 Wm^{-2}. This result suggests the difficulty to evaluate the source of the error of the time-lagged latent heat flux beyond this ambiguity.

These results obtained in the previous section might be affected by the climate regime of the individual measurements. We compare the latent heat flux derived by AMSR-E with the observation at KEO to validate the instantaneous satellite-derived heat flux (Fig. 4) in the mid latitude condition. As the boundary layer parameters are observed simultaneously by AMSR-E, the instantaneous value of the latent heat flux can be obtained.

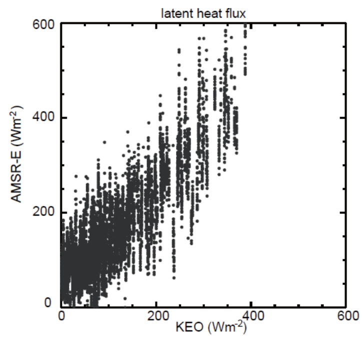

Figure 4 Scatter plot of the 5181 collocations of the instantaneous latent heat flux derived by AMSR-E and that derived at KEO buoy from 2004 to 2007.

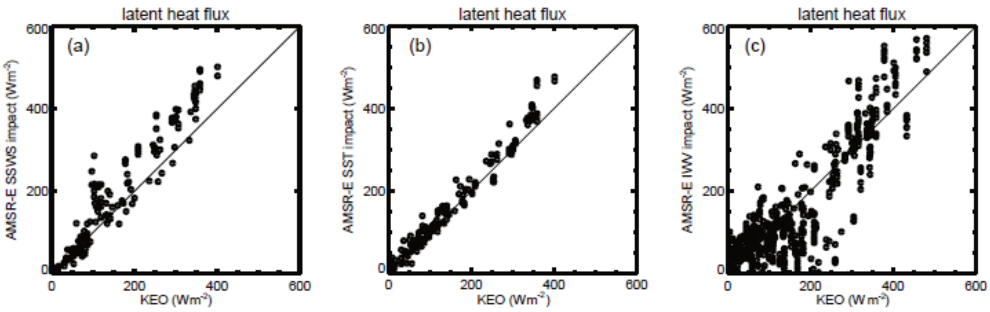

Figure 5 Comparisons of the latent heat flux derived at KEO and the latent heat flux computed by substituting AMSR-E-derived parameters for (a) the SSWS, (b) the SST and (c) the specific

Therefore, the main reason for the disagreement between the in situ latent heat flux and the satellite-derived latent heat flux is attributable to the accumulation of the estimation error of individual parameters. Comparison is made using 5181 collocations of the KEO and AMSR-E observations. The mean difference and the standard deviation are 28.9 Wm^{-2} ± 41.9 Wm^{-2}, respectively. The satellite-derived latent heat flux tends to overestimate when the latent heat flux is large. This is consistent with the tendency of the U_K, which is likely to be overestimated in winter.

Figure 5 shows the impact of errors of individual boundary layer parameters on the latent heat flux, by the sensitivity analysis comparing the in situ latent heat flux with that derived by substituting satellite-derived parameters for one parameter in eq.(1). The impacts of the estimation error of individual variables of the SSWS, the SST and the specific humidity are respectively 3.7 Wm^{-2} ± 24.1 Wm^{-2}, 11.6 Wm^{-2} ± 20.7 Wm^{-2} and 11.1 Wm^{-2} ± 43.8 Wm^{-2}. The error of the SSWS (U_K) has the smallest impact possibly because of the successful correction of the RWD effect. However, the tendency of the error of U_K shown in Fig. 4 is almost the same as that of the SST. The similar tendency of these impacts suggests a multiplier effect of these errors. In fact, Fig.5 shows that both the SST and the SSWS error tend to make a larger overestimation in larger latent heat flux regime. A large bias in the error of the AMSR-E latent heat flux should be affected by that. See more details in Konda et al. (2009).

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REFERENCES

Clayson, C. A. and D. Weitlich, 2007: Variability of tropical diurnal sea surface temperature, *J. Climate*, 20, 334 - 352.

Cronin, M. F., C. Meining, C. L. Sabine, H. Ichikawa and H. Tomita, 2008: Surface mooring network in the Kuroshio Extension, *IEEE Systems Journal Special Issue GEOSS Creating a Global System of Systems*, 2, 424 – 430, doi:10.1109/JSYST.2008.925982.

Fairall, C. W., E. F. Bradley, J. E. Hare, A. A. Grachev and J. B. Dobson, 2003: Bulk parameterization of air-sea fluxes: Updates and verification for the COARE algorithm, *J. Climate*, 16, 571 - 591.

Konda, M. and A. Shibata, 2004: An experimental approach to correct the microwave radiometer wind speed affected by the change of the brightness temperature due to the relative wind direction, *Geophys. Res. Lett.*, 31, L09302, doi:10.1029/2004GL019487.

Konda, M., A. Shibata, N. Ebuchi and K. Arai, 2006: A correction of the effect of relative wind direction on the wind speed derived by Advanced Microwave Scanning Radiometer, *J. Oceanogr.*, 62, 395 - 404.

Konda, M., H. Ichikawa and H. Tomita, 2009: Wind speed and latent heat flux retrieved by simultaneous observation of multiple geophysical parameters by AMSR-E, *J. the Remote Sens. Soc. Jap.*, 29, (in print).

List, R. J., 1949: Smithsonian Meteorological Tables, *6th ed. Smithsonian Institution Press*, 350 pp.

Liu, W. T. and P.P. Niiler, 1984: Determination of monthly mean humidity in the atmospheric surface layer over oceans from satellite data, *J. Phys. Oceanogr.*, 14, 1451 – 1457.

Liu, W. T., X. S. Xie, P. P. Niiler, 2007 Ocean-atmosphere interaction over agulhas extension meanders, *J. Climate*, 20, 5784 - 5797.

Liu, W. T. and X. S. Xie, 2008: Ocean-atmosphere momentum coupling in the Kuroshio Extension observed from space, *J. Oceanogr.*, 64, 631 – 637.

McPhaden, M. J., 1995: The Tropical Atmosphere Ocean Array is Completed, *Bul. Ame. Meteor. Soc.,* 76, 739 - 741.

Wentz, F. J., 1992: Measurement of oceanic wind vector using satellite microwave radiometers. *IEEE Trans. Geo. Remote Sens.*, 30, 960 - 972.

Wentz, F. J., 1997: A well-calibrated ocean algorithm for SSM/I, *J. Geophys. Res.*, 102, 8703 - 8718.